

Harvesting boreal mixedwood stands to favour conifer regeneration:

project establishment and early results



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**Harvesting boreal mixedwood
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project establishment and early results

by

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Abstract

Silvicultural trials were established near Chapleau and Cochrane in northern Ontario to investigate techniques for enhancing the conifer component in boreal mixedwood stands. Approximately 20 ha were experimentally harvested in each area, and artificial regeneration treatments were implemented on the cut blocks at the Chapleau site. Assessments of crop trees and other vegetation are planned for at least 20 years following harvesting. Thus, the locations, designs, layouts, and methods are documented to facilitate remeasurement by future investigators.

The Chapleau trial produced similar harvesting and skidding productivity for clearcutting and partial cutting. Windthrow losses were high for residual trees greater than 10 cm in diameter. The third-year survival of planted white spruce (*Picea glauca* [Moench] Voss) and jack pine (*Pinus banksiana* Lamb.) was affected by harvesting level but not by weeding frequency. Scalping produced no significant responses in seedlings or other vegetation. There was a strong interaction between harvesting and weeding for most response variables. For example, the effect of weeding on seedling height and diameter increased with harvesting intensity. Single weeding following a 50% cut was as effective in reducing hardwood height and density as multiple weeding following a clearcut. Partial cutting improved species richness, while weeding reduced it.

Harvesting productivity in the Cochrane trial was higher for clearcutting than partial cutting, but skidding productivity was similar for both treatments. Logging damage was higher for clearcutting than partial cutting, but there was no difference in damage from natural causes between the harvesting levels. The post-harvest stocking of understory conifers was similar in partially cut and uncut plots, but lower in clearcut plots. Clearcutting produced 44,000 hardwood stems ha⁻¹ the first year after cutting, which was more than double the densities after partial cutting. Harvesting had a larger relative effect on understory light intensity than on soil temperature.

Partial cutting is recommended for producing a boreal mixedwood stand with a viable conifer component in the subsequent rotation. Conifers should be planted under the residual stand if advance growth is lacking. Otherwise, the stand should be carefully logged to preserve the conifer advance growth. Partial cutting and careful logging in mixedwood stands are economically feasible, but require multi-rotation planning and adequately trained operators. The early results from these trials are subject to confirmation through long-term monitoring.

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Introduction

Boreal mixedwood sites are typically dominated by hardwoods soon after major disturbances such as clearcutting (Perala 1989). Alternative harvesting methods may help reduce the level of competition in the regeneration environment. For example, it appears that optimum conditions for establishing white spruce (*Picea glauca* [Moench] Voss) in mixedwood stands are produced by shelterwood cutting combined with subsequent vegetation control (Groot 1999). The challenge is to enrich the conifer content enough to produce desired mixtures of crop species.

Mixedwood sites near Chapleau and Cochrane were selected to test approaches for maintaining or increasing the conifer component in hardwood-dominated stands. Both trials relied on the cooperation of local industry partners to experimentally harvest the stands. Remeasurements of crop trees and other vegetation are planned at 5- to 10-year intervals for at least 20 years following harvesting to track volume productivity, stand structure, and vegetation succession.

The objectives of this report are to 1) explain the context and rationale for the mixedwood field trials; 2) document the locations, designs, layouts, and methods to facilitate reassessments over the long term, perhaps by other investigators; and 3) present responses occurring during the first 3 years after treatment. The results are preliminary and do not fully test the hypotheses underlying these trials. However, they are included to provide guidance to resource managers, who have insufficient information for reliable mixedwood prescriptions in the forest management planning process.

The Mixedwood Resource

The Boreal Mixedwood Forest is an ecologically and economically valuable component of Ontario's forested landscape. It occupies half of the productive forest land within the southern part of Boreal Forest Region and northern part of Great Lakes-St. Lawrence Forest Region (McClain 1981). This amounts to approximately 160,000 km² of mixedwood forest.

A boreal mixedwood site is an area with climatic, topographic, and edaphic conditions that favour the production of closed canopies dominated by trembling aspen (*Populus tremuloides* Michx.) or white birch (*Betula papyrifera* Marsh.) in early successional stages, black spruce (*Picea mariana* [Mill.] B.S.P.) or white spruce in mid-successional stages, and balsam fir (*Abies balsamea* [L.] Mill.) in late successional stages (MacDonald and Weingartner 1995). Commonly associated species include jack pine (*Pinus banksiana* Lamb.), white pine (*Pinus strobus* L.), red pine (*Pinus resinosa* Ait.), eastern white cedar (*Thuja occidentalis* L.), tamarack (*Larix laricina* [Du Roi] K. Koch), largetooth aspen (*Populus grandidentata* Michx.), balsam poplar (*Populus balsamifera* L.), white elm (*Ulmus americana* L.), black ash (*Fraxinus nigra* Marsh.) and black willow (*Salix nigra* Marsh.) (MacDonald and Weingartner 1995).

Boreal mixedwood stands typically occur on well drained, fertile, calcareous, intermediate- to fine-textured soils that have good incorporation of organic matter and are located on mid-slope positions (Pierpoint 1981). These site characteristics favour high timber volume productivity and biological diversity.

Boreal mixedwood forests have not been strategically managed or utilized, leaving their potential largely untapped. However, attitudes are changing in Ontario as the province seeks to reduce the cost of forest renewal and adopt sustainable, ecosystem-based practices. Mixed forests offer many advantages in terms of economic wood supply, aesthetics, wildlife habitat, pest resistance, and nutrient cycling (MacDonald 1995). The mixedwood management philosophy advocates adapting to successional changes rather than resisting them (Weingartner and MacDonald 1995). This approach promotes biological diversity by relying on partial cutting and natural regeneration, and minimizing the use of herbicides.

Mixedwood stands are gaining attention because they represent an attractive source of high-quality fibre close to mills, while accessible pure stands of spruce and pine are diminishing. Ontario is facing a pronounced shortfall of conifer stands in the 21- to 40-year age class (Ontario Ministry of Natural Resources 1996). This wood supply shortage could be partially offset by increasing the utilization of conifers occurring as understory species in mixedwood stands.

Rationale for Boreal Mixedwood Trials

The sustained expansion of mixedwood cover types in northern Ontario (Hearnden *et al.* 1992) has highlighted the need to develop silvicultural guidelines for these forests. Thus, the terms and conditions of the environmental assessment for timber management in Ontario require the Ontario Ministry of Natural Resources to produce a mixedwood silvicultural guide to be used in the timber

management planning process (Koven and Martel 1994). However, the development of reliable guidelines will require more applied knowledge about mixedwood ecology and silviculture.

Several recent symposia on boreal mixedwood management have emphasized the need for new information on species utilization, alternative harvesting and regeneration systems, stand dynamics, and integrated resource use (Samoil 1988, Shorttreid 1991, Comeau and Thomas 1996, Smith and Crook 1996). Experience in western Canada indicates that the lack of accurate growth and yield information impedes mixedwood management (Navratil *et al.* 1991). A formal survey of mixedwood stakeholders in Ontario identified the need for better understanding of ecosystem function and species-site relationships, and better information on management techniques such as partial cutting, site preparation, underplanting, and competition control (Weingartner and MacDonald 1994).

The research trials outlined in the following sections were established to address some of the knowledge gaps in boreal mixedwood management. Two upland mixedwood sites with differing stand structures were selected to test the effects of modified harvesting and other silvicultural treatments on stand renewal and development.

Chapleau Trial

Objectives

The main objective of this trial was to test the effects of harvesting intensity, weeding frequency, and localized site preparation on the survival and growth of planted white spruce

and jack pine seedlings in mixedwood stands dominated by trembling aspen. The effects of the treatments on vegetation succession and understory microclimate were also monitored.

It should be possible to maintain desired conifers by emulating disturbances that are appropriate for the autecology of each species. Shade-tolerant species such as white spruce should respond well to a gradual opening of the canopy, while intolerant species such as jack pine likely require maximum canopy opening from the time of establishment. Both conifer species should benefit from local exclusion of competition (to enhance light and nutrient availability) and scalping to produce mineral soil for the rooting medium at the time of planting (to enhance moisture availability).

Site Description

The trial was established in a mid-successional boreal mixedwood stand north of Chapleau, Ontario, at 47°59' north latitude, 83°25' west longitude (Figure 1). According to

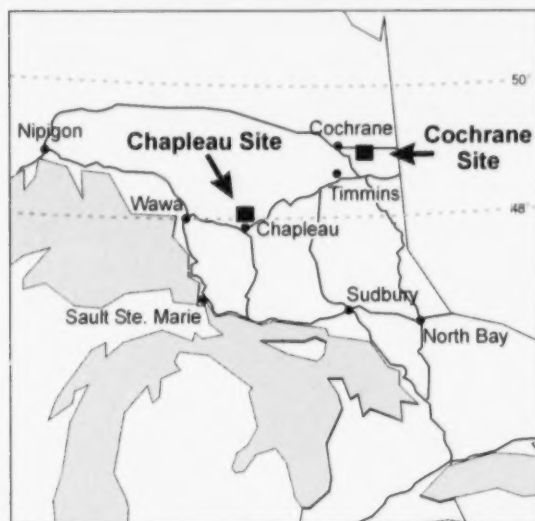


Figure 1. Location of the mixedwood trials near Chapleau and Cochrane, Ontario.

the Northeastern Ontario Forest Ecosystem Classification System (McCarthy *et al.* 1994), the site type is 6c (Hardwood Mixedwood - Coarse Soil). Initial overstory characteristics of the stand are summarized in Table 1.

Understory vegetation was predominantly balsam fir, white spruce, and hardwood shrubs such as mountain maple (*Acer spicatum* Lam.) and beaked hazel (*Corylus cornuta* Marsh.), on fresh to moist, non-calcareous, coarse loamy soils.

Table 1. Original stand characteristics on the Chapleau site, showing means for all treatments combined.

Species	Basal age (years)	Height (m)	Basal area (m ² /ha)	(%)
Trembling Aspen	71	24.5	26.2	64.4
White Birch	69	21.3	6.6	16.2
Black Spruce	66	16.3	3.0	7.4
White Spruce	62	16.0	0.9	2.2
Jack Pine	71	22.1	2.3	5.6
Balsam Fir	58	15.3	1.7	4.2
Total	-	-	40.7	100.0

Methods

Skid trails, baselines, and plot boundaries were delineated using a survey laser. Four intensities of overstory basal area removal were randomly applied to 112 m x 56 m main plots (Figure 2): 1) uncut; 2) 50% partial cut without removal of residuals; 3) 50% partial cut with residuals removed after 3 years; and 4) clearcut. Three weeding frequencies (none, single, and multiple) and 2 site preparation levels (not scalped and scalped) were randomly applied to 14 m x 14 m sub-plots within each harvested plot (Figure 3). There were 6 replications of all treatment combinations.

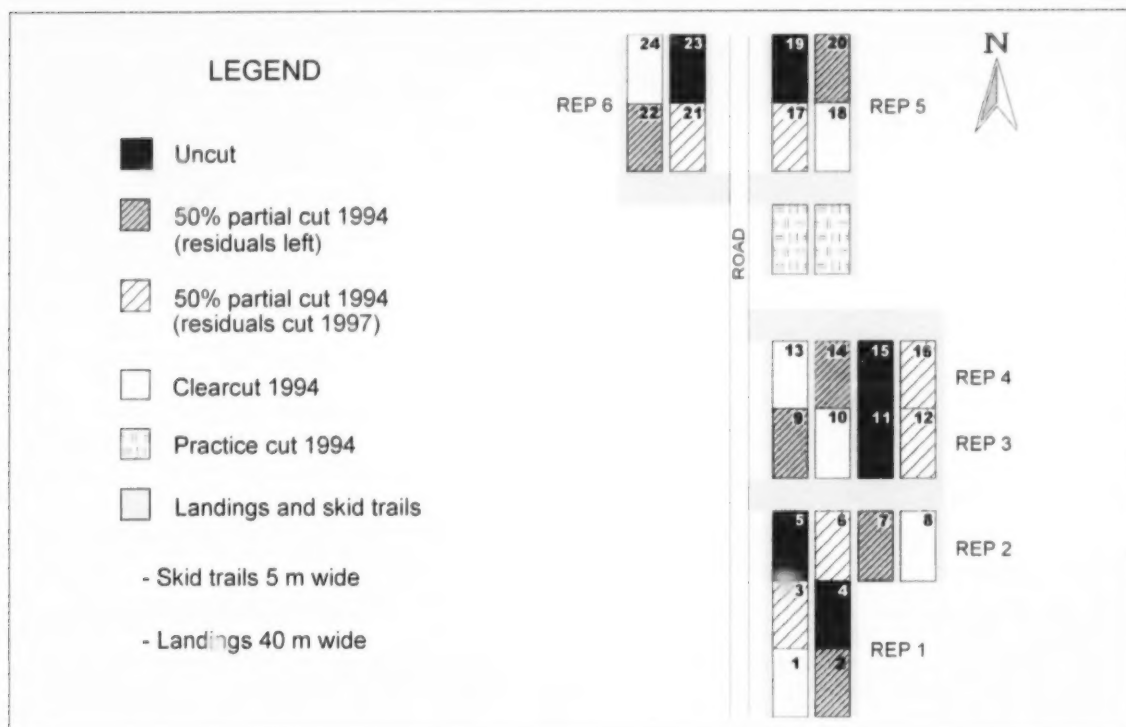


Figure 2. Layout of the Chapleau mixedwood silvicultural trial (not to scale).

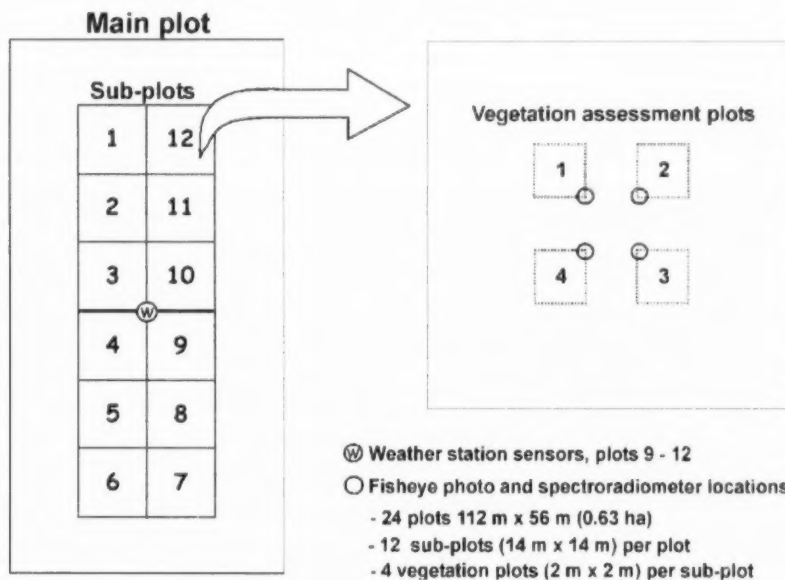


Figure 3. Schematic relationship among the main plots, sub-plots, and vegetation assessment plots in the Chapleau trial.

The main plots were full-tree logged with a feller-buncher and grapple skidder in late winter 1994. Regularly spaced, oblique entries were made into each plot from 5-m-wide skid trails on both sides. Dominant aspen and fir were removed preferentially, with spruce cut only if necessary to achieve the required basal area reductions. The active machine time required to harvest and skid the timber on each plot was recorded.

Careful logging practices minimized damage to the site and residual trees. For example, trees were moved vertically in the cutting head from the stump to the skid trail, machine movement and turning on the cut blocks were controlled, and some trees were left along the skid trails as rub posts. All trees were cut as close to the ground as possible, except where cutting high would prevent damage to adjacent uncut trees. Snow cover and frozen ground reduced soil disturbance, allowing greater control over the site preparation treatments.

Clearcutting removed overstory trees greater than 10-cm DBH (diameter 1.3 m above ground), leaving saplings and advance growth that will form part of the next crop. Some trees exceeding 10-cm DBH remained on clearcut plots after treatment because they were either unmerchantable or could not be removed without damaging large amounts of advance growth.

Sub-plots were each planted with 42 overwintered container seedlings from local seed sources in the spring of 1994, half to white spruce and half to jack pine. Seedlings were planted in a 6 x 7 grid at a spacing of 2 m. Formal testing of stock quality was conducted prior to planting, using the procedures described in Sampson *et al.* (1997). Half of the sub-plots planted to each species were manually scalped before planting by removing the humus layer within a 25-cm radius around each planting spot.

Weeding treatments were conducted by ground spraying Vision[®] herbicide (2.2 kg ha⁻¹ active ingredient) on the sub-plots following bud set of the planted seedlings. The multiple weeding treatment involved spraying annually for the first 5 years after harvesting. The single weeding treatment involved spraying only during the second year.

All trees taller than 4.0 m on the sub-plots were measured annually for survival, DBH, dominance class, and condition. Heights and basal ages were measured on a subsample of overstory trees to help document initial stand conditions (Table 1).

The number of species and percent ground cover of trees, shrubs, herbaceous plants, and bryophytes were tallied annually prior to weeding on 4 vegetation assessment plots (2 m x 2 m) within each sub-plot (Figure 3). Species richness was considered the total species count for all vegetation classes (Ludwig and Reynolds 1988). Densities and heights were also recorded for the trees and shrubs on the vegetation assessment plots. Survival, root collar diameter, leader base diameter, height, crown dimensions, and damage class were measured on all planted seedlings following bud set.

Hemispherical photographs were taken from 4 fixed positions per sub-plot (Figure 3), using a 7.5 mm fisheye lens aimed vertically with the camera levelled on a tripod and the focal plane 33 cm above the ground. Kodak T-Max film (ASA 100) was used. Most of the photographs were taken on uniformly overcast days to avoid the excessive contrast and loss of image detail that can occur when the sun is in the picture. Photographs were transferred to compact disks and assessed with image processing software to obtain percent canopy cover (Figure 4). Light quality was measured by taking a vertical scan of the canopy with a Li-Cor LI-1800 portable spectroradiometer at the locations used for hemispherical photography.

All overstory and understory measurements were conducted for 5 years, beginning in the summer after harvesting. One replication of the harvesting treatments was instrumented to monitor photosynthetically active radiation (1 m above ground), air temperature and relative humidity (2 m above ground), soil temperature (surface and 25-cm depth), soil moisture (25-cm depth), precipitation (50 cm above ground), and wind speed and direction (3.6 m above ground). The status of all variables was automatically recorded every 20 minutes from early May until late September.

A split-plot experimental design was used, with a randomized complete block arrangement of main treatments (harvesting intensities) and a factorial arrangement of secondary treatments (weeding frequencies and scalping levels). Analysis of variance was used to assess the effect of the treatments and interactions on seedling and vegetation response variables.

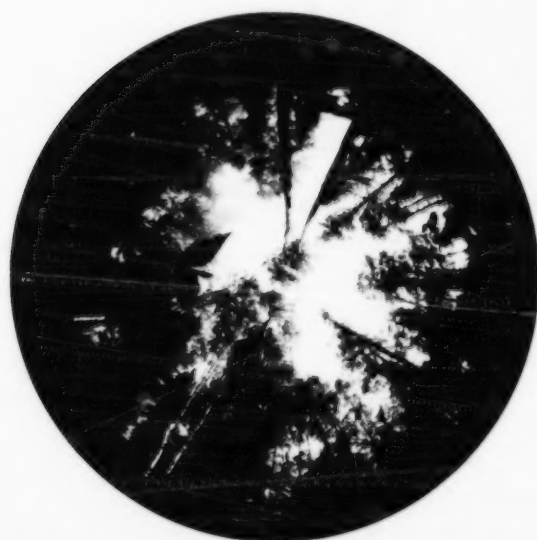


Figure 4. Hemispherical photograph of a mixedwood stand 1 year after partial cutting, from the perspective of a planted seedling. Canopy cover measured with image processing software is 88%.

Overview and Discussion of Preliminary Results

The actual basal area reductions were close to the nominal basal area reductions prescribed for this trial (Table 2). Although clearcutting is often considered the most economically efficient system, the harvesting and skidding productivity of the partial cuts was similar to that of the clearcuts (Table 3) because partial cutting preferentially removed large trees. The operational productivity in this trial is economically acceptable for careful logging operations (J.F. Gingras, pers. comm.).

Windthrow losses 1 year after harvesting were highest for residual trees larger than 10-cm DBH, especially in the clearcut treatments

Table 2. Comparison in 1995 of overstory basal area reductions among harvesting treatments in the Chapleau mixedwood trial.

Treatment	BA ¹ reduction m ² /ha		Percent	
	Mean	SE ²	Mean	SE
50% cut 1994, residuals left	17.9	4.8	49.2	9.1
50% cut 1994, residuals to be cut 1997	14.5	3.5	44.7	4.8
Clearcut 1994	34.1	5.7	96.6	2.9

¹Basal area of residual trees $\geq$ 10-cm DBH.

²Standard error.

Table 3. Harvesting and skidding productivity for the Chapleau mixedwood trial.

Treatment	Productivity (m ³ /hr)	
	Harvesting	Skidding
50% cut, careful logging	25.6	42.4
Clearcut, careful logging	25.3	42.9

(Figures 5 and 6). As explained in the methods section, some large trees were left on clearcut plots because they were either unmerchantable or could not be removed without damaging advance growth. These trees were more susceptible to windthrow than residuals on the 50% cut because they occurred as scattered individuals without the protection of adjacent crowns. Initially conifers sustained the most wind damage, but losses of dominant aspen in the partial cuts increased during the subsequent 2 years.

Viability of seedling stock was confirmed by testing physiological attributes such as root-growth potential before the stock was planted. Third-year survival of white spruce was greater than that of jack pine for all treatments. Survival was affected by harvesting, but not by weeding (Table 4). Survival in the uncut treatment was low for both species (55% for spruce, 40% for pine), but it increased to



Figure 5. Residual trees larger than 10-cm DBH were susceptible to windthrow.

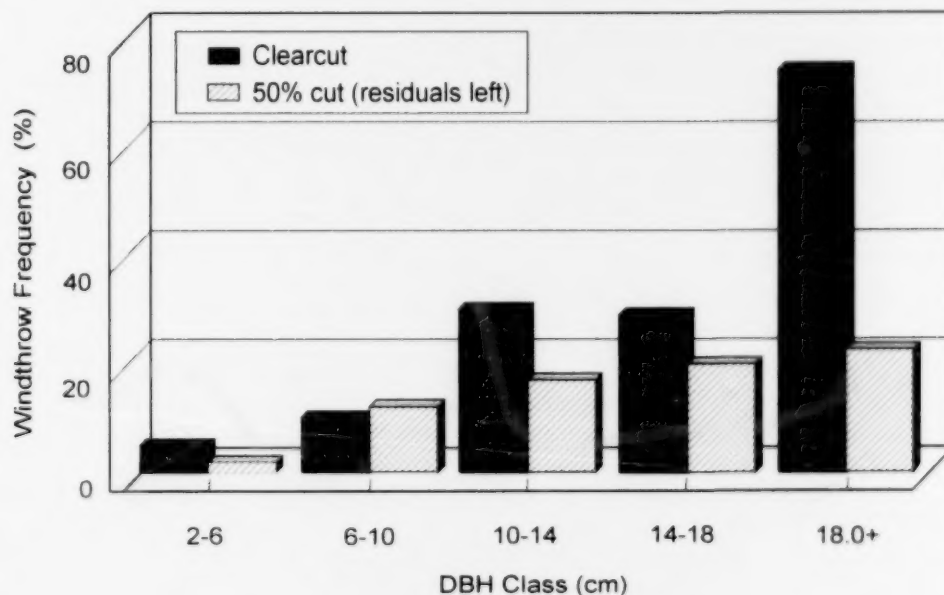


Figure 6. Frequency distribution of windthrown conifers on the Chapleau site 1 year after harvesting.

Table 4. Probability-levels for third-year responses of white spruce (Sw) and jack pine (Pj).

Response Variable	Treatments							
	Scalping		Harvesting (H)		Weeding (W)		H x W	
	Sw	Pj	Sw	Pj	Sw	Pj	Sw	Pj
Survival	0.14	0.06	<0.01	<0.01	0.90	0.59	0.48	0.51
Height	0.13	0.28	<0.01	<0.01	<0.01	0.02	<0.01	<0.01
Root collar diameter	0.62	0.42	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Table 5. Probability-levels for third-year vegetation responses.

Response Variable	Treatments			
	Scalping	Harvesting (H)	Weeding (W)	H x W
Height of understory hardwoods	0.22	<0.01	<0.01	<0.01
Density of understory hardwoods	0.69	<0.01	<0.01	<0.01
Species richness	0.94	0.03	<0.01	0.30

acceptable levels in harvested plots (90% for spruce, 80% for pine). Scalping produced no significant responses in seedlings or other vegetation (Tables 4 and 5).

Significant interaction effects in a split-plot design reduce the importance of the main effects (Dowdy and Wearden 1983). Thus, the interactions were examined to determine how treatment combinations influence the responses. Interactions occurred between harvesting and weeding for seedling height and diameter and understory hardwood height and density (Tables 4 and 5). For example, the positive effect of weeding on seedling diameter and the negative effect of weeding on hardwood height increased with harvesting intensity.

The best diameter growth was associated with clearcutting followed by multiple weeding (Figure 7). This agrees with Wagner *et*

al. (1996), who found that diameter growth was proportional to weeding frequency for seedlings of jack pine, black spruce, white pine, and red pine. Height response to weeding was less pronounced than diameter response, confirming the finding of other studies that height is less competition-sensitive than diameter (MacDonald *et al.* 1990, Wagner *et al.* 1996, Lautenschlager 1999).

Understory hardwood density increased from 2,800 ha⁻¹ (mean height 15 cm) in the uncut treatment to 14,000 ha⁻¹ (68 cm) in the 50% cut and 28,000 ha⁻¹ (122 cm) in the clearcut. Thus, preventing hardwood dominance may require some vegetation control even when a stand is only partially cut. However, a single weeding following a 50% cut was as effective as multiple weeding following a clearcut. Each resulted in 5,000 hardwood stems ha⁻¹ with a mean height of 30 cm.

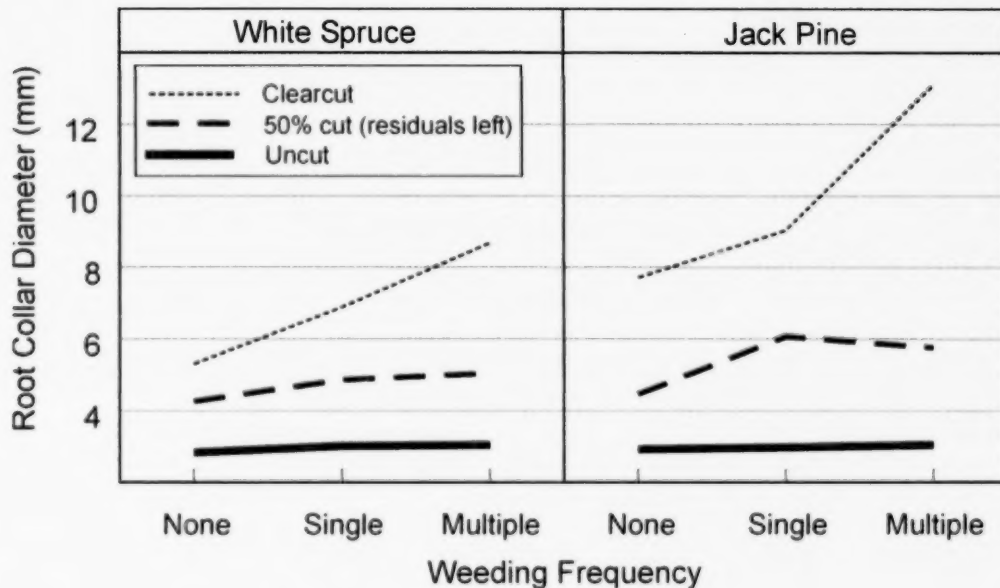


Figure 7. Root collar diameter response to weeding and harvesting after 3 years.

Harvesting and weeding produced small but significant third-year responses in species richness (Table 5). Vegetation assessment plots in the 50% partial cut averaged 2 species richer than plots in the other harvesting intensities. Hannerz and Hanell (1997) found similar trends on peatland sites. Single weeding reduced species richness by 1 to 2 and multiple weeding reduced species richness by 2 to 3.

Management Applications

Partial cutting to maintain conifers in mixedwood stands does not necessarily decrease machine productivity, compared to clearcutting in similar stands. Based on the survival data during the first 3 years after treatment, it appears that white spruce is more suitable than jack pine for understory planting. On sites with inadequate conifer advance growth, planting without scalping should follow the removal of 50% of the overstory.

Removing more than 50% of the overstory could unacceptably increase the windthrow risk to residual trees on some sites.

Clearcutting followed by annual weeding for at least 3 years maximizes the growth of planted conifers. Herbicide use can be minimized while maintaining a viable conifer component in mixedwoods by underplanting a 50% partial cut and applying a single weeding after the second growing season. This treatment combination is recommended where sustaining understory species richness is an important management objective.

Cochrane Trial

Objectives

The objectives of this study were to 1) test the effect of basal area reduction in mature aspen stands on the survival, growth, and

quality of conifer regeneration, aspen suckers, and non-crop woody and herbaceous vegetation; 2) develop individual-tree, distance-dependent competition models to predict the optimum stand structures for regenerating desired mixtures of conifers and hardwoods; and 3) monitor the influence of harvesting on microclimatic factors that may be important to regeneration success. In contrast to the trial near Chapleau, the Cochrane trial does not include planting and tending operations because conifer advance growth is more abundant on this site.

Harvesting intensity is an important silvicultural tool for directing succession and achieving desirable stand structures and growth rates in boreal mixedwood stands. Partial cutting may favour advance conifer regeneration, reducing the need for artificial regeneration and herbicides to control hardwoods. Heavy cutting in aspen-dominated mixedwood stands would likely promote the development of aspen and other early-successional tree and shrub species. Light cutting would promote succession to understory shade-tolerant conifers by releasing them and providing protection against windthrow, while limiting the conditions for aspen suckering and shrub germination.

Extreme values of microclimatic factors (such as light level, air temperature, soil temperature, soil moisture, and wind speed) likely increase in proportion to harvesting intensity. The residual overstory after partial cutting should improve the survival and growth of conifer regeneration by moderating microclimatic extremes.

Site Description

The trial was established in a mid-successional boreal mixedwood stand east of Cochrane, Ontario, at 49°04' north latitude,

80°26' west longitude (Figure 1). According to the Northeastern Ontario Forest Ecosystem Classification System (McCarthy *et al.* 1994), the site type is primarily 6a (Mixedwood - Fine Soil), with some inclusions of 7a (Hardwood - Fine Soil) and 10 (Hardwood - Moist Soil). Initial overstory characteristics of the stand are summarized in Table 6. The stand is highly productive, with an initial volume of 302 m³/ha for all hardwood species, and 93 m³/ha for all conifer species. Understory vegetation was predominantly balsam fir, black spruce, and hardwood shrubs such as speckled alder (*Alnus rugosa* [DuRoi] Spreng.), mountain maple, and beaked hazel, on fresh to very moist clay soils.

Methods

A randomized complete block experimental design was used. There were 3 harvesting treatments, each applied with careful logging around the advance regeneration (as described for the Chapleau trial). The treatments removed 0, 40, and 100% of the merchantable overstory basal area (based on trees $\geq$ 10-cm DBH), and

Table 6. Original stand characteristics on the Cochrane site, showing means for all treatments combined.

Species	Basal age (years)	Height (m)	Basal area (m ² /ha)	(%)
Trembling Aspen	73	22.4	25.8	71.3
White Birch	43	4.1	0.1	0.3
Black Spruce	72	13.3	5.4	14.9
White Spruce	71	12.0	1.2	3.3
Jack Pine	75	23.0	2.5	6.9
Balsam Fir	59	4.8	1.2	3.3
Total	-	-	36.2	100.0

were randomly assigned to 4 plots (1 plot each for 0 and 100% reductions and 2 plots for 40% reduction) within each of 4 replications (Figure 8). For the 40% harvesting level, 25% of the overstory basal area in the 16-m-wide leave strips was removed. When combined with the clearcutting of the 5-m-wide skid trails, this resulted in the correct overall basal area reduction.

Each harvested plot measures 100 m x 100 m (1.0 ha) and contains a central circular overstory assessment plot with a radius of 25 m (0.2 ha) (Figure 8). Twelve vegetation assessment plots (2 m x 2 m) are equally spaced on the circumference of the circular plot (Figure 9).

The plots were full-tree logged with a feller-buncher and grapple skidder during January and February 1995. Each plot was harvested by extending the cutting head halfway into 16-m-wide strips from 5-m-wide skid trails on each side (Figure 8). Large aspen and fir were harvested first, with spruce cut only if necessary to achieve the required basal area reductions. As in the Chapleau trial, some overstory trees remained on the clearcut plots after treatment because they were either unmerchantable or could not be removed without damaging advance growth. Harvesting was designed to distribute the residual overstory canopy as uniformly as possible in each partially cut plot. The active machine time required to harvest and skid the timber on each plot was recorded.

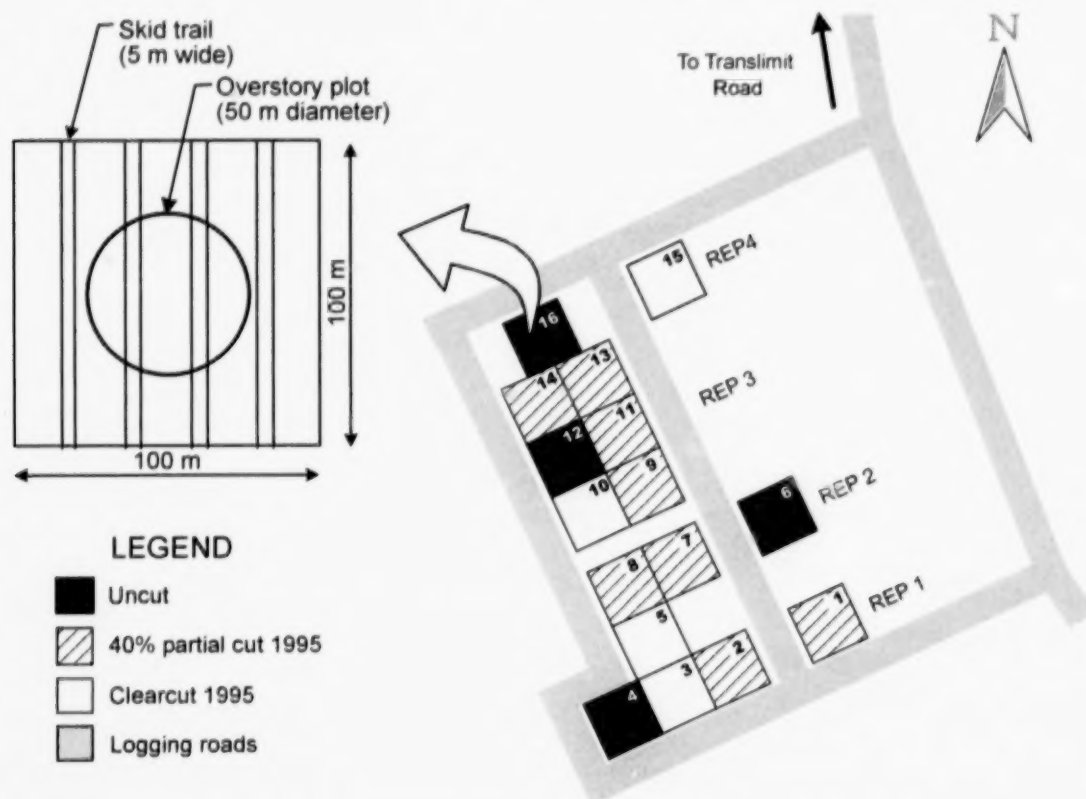


Figure 8. Layout of the Cochrane mixedwood silvicultural trial (not to scale).

All trees taller than 4.0 m within the overstory assessment plots were mapped prior to the harvesting operation by measuring their distances and azimuths from the plot centre, using a survey laser. The DBH, total height, crown length, crown radius in each of 4 directions, degree and direction of stem lean, dominance class, survival class, and damage class were measured each July or August on all mapped trees. Basal ages were measured on a subsample of overstory trees to help document initial stand conditions (Table 6). Permanent tags were attached to all residual trees after the harvesting treatments were complete. Additional trees reaching 4 m in height were tagged and measured at each annual

reassessment. Plants on the vegetation assessment plots were tallied annually using the methods described for the Chapleau trial.

A defoliation survey was conducted annually from 1997 to 1999 inclusive, in response to an outbreak of forest tent caterpillar (*Malacosoma disstria* Hübner). The survey was implemented after completion of caterpillar feeding activity and before refoliation of damaged trees. Crown defoliation was visually rated on aspen trees in the overstory assessment plots, using 10 classes from 0% to 100%. All live aspen in uncut and partially cut plots were assessed for damage, and 25 of the tallest aspen suckers in the clearcut plots were assessed.

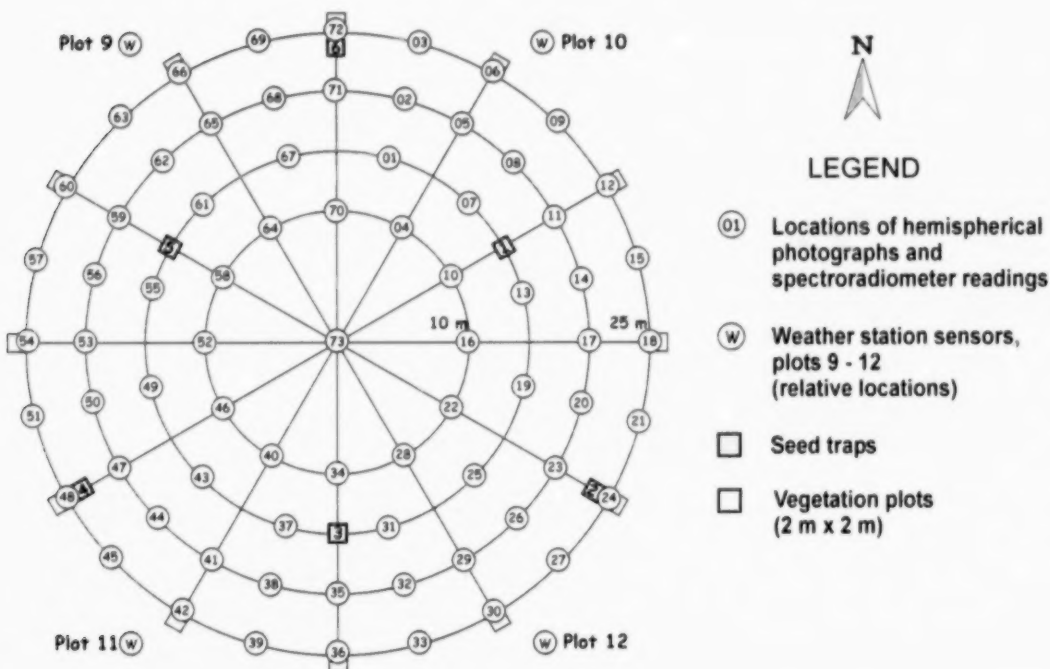


Figure 9. Details of the assessment plots in the Cochrane mixedwood trial.

Hemispherical photographs and spectroradiometer readings were taken from fixed positions adjacent to the vegetation assessment plots and from other fixed positions in each overstory assessment plot (Figure 9). The methods outlined for the Chapleau trial were applied, except that a camera height of 1.3 m was used for hemispherical photographs to reduce interference from advance regeneration.

Six seed traps (each 0.3 m² surface area) were installed in each overstory assessment plot during the summer prior to harvesting. Seed was collected annually at the end of each month during summer and fall. The number of seeds was recorded by species and location for each collection period, and the corresponding percent viability was determined through germination trials.

All overstory and understory measurements were conducted for 5 years, beginning in the summer after harvesting. Microclimatic variables were automatically recorded on 1 replication of the treatments (Figure 10), as described for the Chapleau trial.

An extra replication of the trial was established in a similar but more accessible boreal mixedwood stand 30 km south of the main installation. This 5-ha demonstration area includes a walking trail with signs at points of interest to illustrate mixedwood ecology and management to resource managers and the public (Figure 11).

Analysis of variance was used to assess the significance of the responses to harvesting intensity. The response variables of understory and residual overstory trees include survival, height growth, diameter growth, animal damage, and seedfall. The response variables of understory non-crop vegetation include height, density, species richness, and ground cover.

Overview and Discussion of Preliminary Results

The actual basal area reductions were close to the nominal basal area reductions of 40% and 100% (Table 7). The original design included 36% and 68% reductions, but these prescriptions were not achieved. Since the 68% stands were under-harvested, the 2 partially cut treatments were combined into a nominal 40% removal. The under-harvesting likely resulted from the need to substitute smaller trees close to the skid trails for intended target trees whose size and distance exceeded the capacity and reach of the cutting head. Under-harvesting was not a problem in the Chapleau trial (Table 2) because the operator was permitted to leave the skid trails, providing better access to target trees or more appropriate substitute trees.



Figure 10. Several microclimatic variables were automatically recorded on 1 replication of the 4 harvesting treatments.

Table 7. Comparison in 1996 of overstory basal area reductions among harvesting treatments in the Cochrane mixedwood trial.

Treatment	BA ¹ reduction			
	Mean	SE ²	Mean	SE ²
40% cut 1995	15.2	3.6	42.5	7.6
Clearcut 1995	36.2	1.3	96.2	2.7

¹Basal area of residual trees $\geq$ 10-cm DBH.

²Standard error.

Table 8. Harvesting and skidding productivity for the Cochrane mixedwood trial.

Treatment	Productivity (m ³ /hr)	
	Harvesting	Skidding
40% cut, careful logging	27.8	27.2
Clearcut, careful logging	35.2	25.1

Harvesting productivity increased with the amount of overstory removed, but skidding productivity was similar for the 2 harvesting levels (Table 8). Since these productivity levels approximate those of many conventional boreal operations (J.F. Gingras, pers. comm.), modified harvesting to favour conifers in mixedwood stands may be economically acceptable.

The proportion of residual understory trees with logging damage was higher for the clearcut than for the partial cuts (Figure 12). Furthermore, the stocking of understory conifers after 2 years was similar in partially cut and uncut plots, but lower in clearcut plots (Figure 13). Partial cutting allows the operator to select overstory trees that can be carefully removed, minimizing understory damage.



Figure 11. A 5-ha demonstration area was established to illustrate ecological and operational aspects of this project.

There was no significant difference in damage from natural causes among the harvesting levels (Figure 12). Windthrow damage was common for residual conifers 10 to 20 m tall, especially after clearcutting. Forest tent caterpillar defoliation reached approximately 60% for crowns of overstory aspen and 85% for crowns of aspen suckers before declining in 1999 (Table 9). No mortality can be directly attributed to the defoliation, but subsequent analyses will adjust overstory removal levels to account for the sparser crown foliage.

Harvested plots had higher hardwood stocking than uncut plots after 2 years, and hardwood densities after clearcutting (44,000 stems ha⁻¹) were more than double the densities after partial cutting. Clearcut plots also had higher shrub stocking than uncut plots, while partially cut plots had lower shrub stocking (Figure 13).

Understory light intensity was strongly affected by harvesting (Figure 14). The effect seems to be non-linear, with the 40% cut producing a 100% increase in light intensity, and the clearcut producing a 500% increase. Thus, manipulation of the light regime through basal area adjustment could be an important tool for controlling vegetation succession and regeneration performance. The challenge in modified harvesting is to enhance light intensity enough to favour the growth of the conifer understory without promoting excessive hardwood growth. The increase in mean light intensity in 1997 is likely attributable to windthrow removing some residual trees. Understory light intensity may begin to decline in the harvested stands as advance growth and aspen suckers increase in height and crown volume.

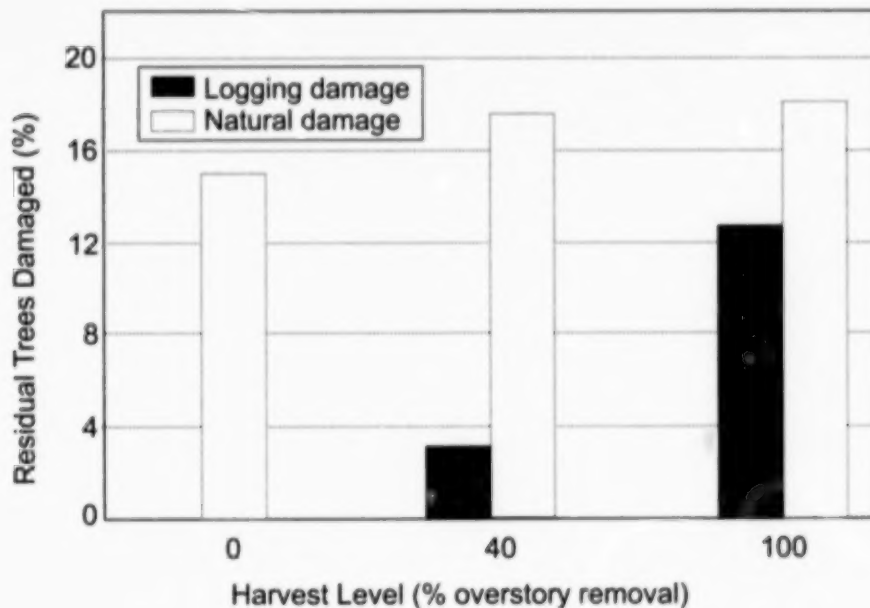


Figure 12. Damage to the residual trees 1 year after cutting.

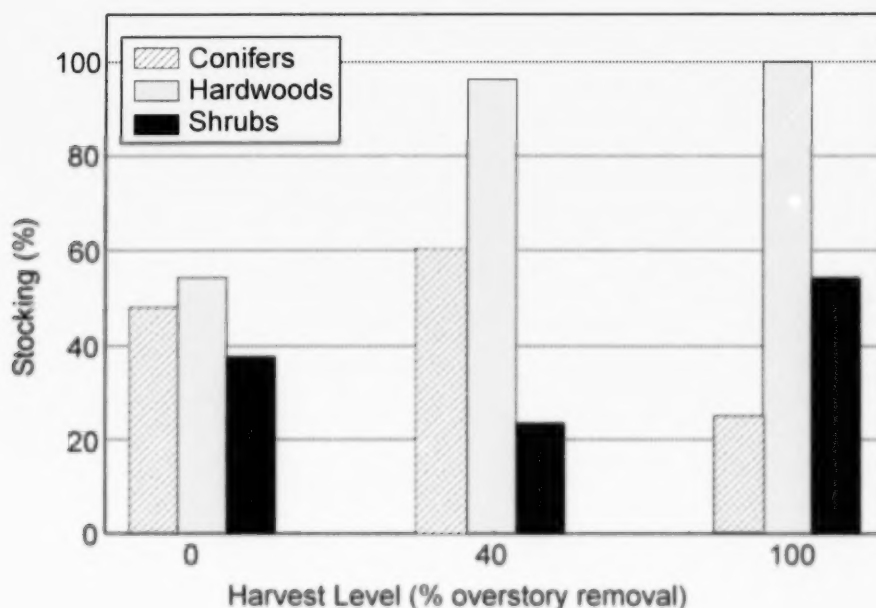


Figure 13. Effects of harvesting level on understory stocking 2 years after cutting.

Mean surface soil temperature was similar for the uncut and 40% cut treatments and slightly higher for the clearcut (Figure 15). The decline in mean soil temperature for all treatments in 1997 was likely caused by a regionally cooler growing season that year. The effect of overstory removal on soil temperature was likely counteracted by understory vegetation. Careful logging in multi-storied

boreal mixedwood stands leaves saplings, advance growth, and low vegetation that reduce ground-level insolation, and hence warming, even in clearcuts. Soil warming can be beneficial because it promotes root growth and nutrient cycling (Raison 1979, Andersen *et al.* 1986). If cold soil in the spring is a limiting factor, maximum overstory opening followed by vegetation control may be required.

Table 9. Aspen defoliation by forest tent caterpillar on the Cochrane mixedwood plots.

Treatment	Defoliation (%)					
	Mean	1997 SE ¹	Mean	1998 SE	Mean	1999 SE
Uncut ²	55.4	18.5	64.8	22.0	51.5	7.7
40% cut ²	63.3	11.5	58.2	11.9	52.4	7.8
Clearcut ³	7.0	2.7	85.1	16.6	19.1	7.2

¹Standard error.

²All residual aspen on each overstory assessment plot were rated for defoliation level.

³25 regenerating aspen suckers on each overstory assessment plot were rated for defoliation level.

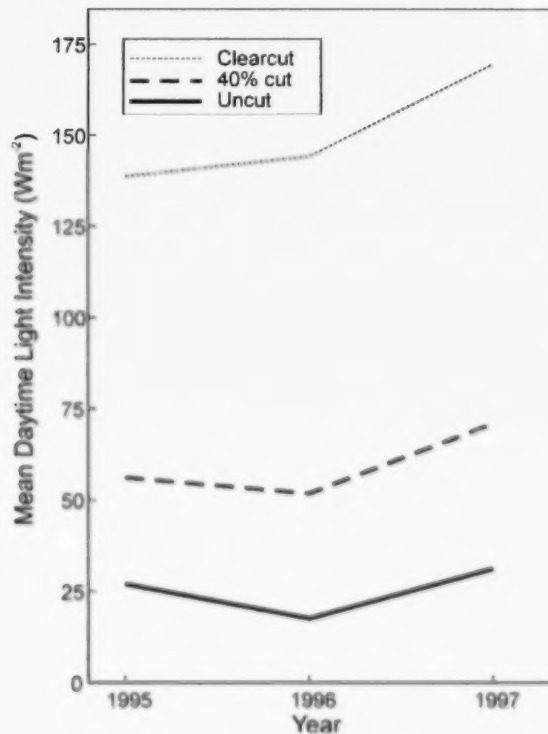


Figure 14. Mean daytime light intensity (7:00 to 19:00 hours) below the canopy during the second growing season after treatment.

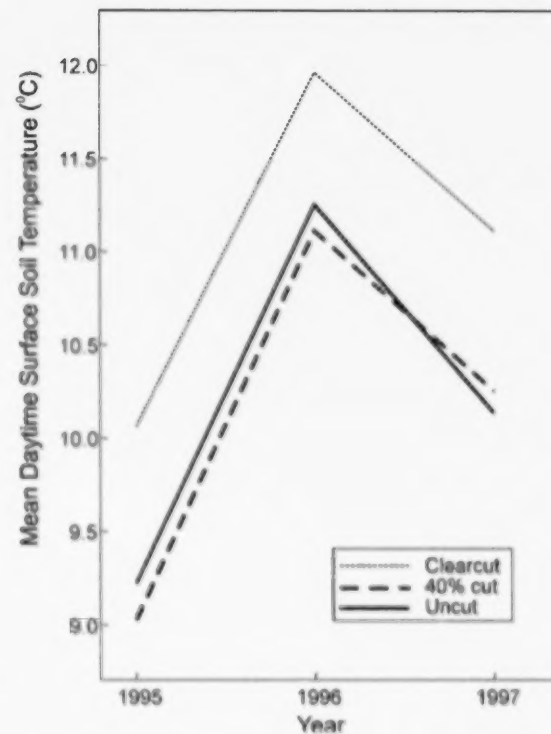


Figure 15. Mean daytime surface soil temperature (7:00 to 19:00 hours) during the second growing season after treatment.

Management Applications

Based on initial post-treatment observations, a basal area reduction of 40% in boreal mixedwood stands appears to be an economically acceptable practice that inhibits the development of understory hardwood trees and shrubs, maintains conifer advance growth, minimizes windthrow losses, and moderates the microclimate in the regeneration environment. Implementing this

harvesting level with careful logging techniques results in minimal damage to advance growth and residual trees. When conifer stocking targets are achieved, the residual overstory can be either removed to accelerate conifer development or left for wildlife habitat. However, equipment used in secondary harvest entries should be restricted to previous skid trails to minimize crop tree damage.

Conclusions

Early results from the trials documented in this report provide guidance for boreal mixedwood management. For example, partial cutting using careful logging to protect residual trees and advance regeneration is recommended as an option for increasing the conifer component. Canopy manipulation is an important tool for controlling understory species composition and regeneration performance. However, achieving the desired basal area reduction in uneven-aged mixedwood stands relies on appropriate equipment, careful design of cutting patterns, and adequately trained and experienced operators.

The variation in harvesting and skidding productivity between the sites can be attributed to differences in equipment, operator experience, terrain, and cut block layout. However, the productivity on both sites was economically acceptable and would likely improve without the constraints of a research design.

These trials confirm the effectiveness of clearcutting followed by multiple weeding for promoting the survival and growth of conifer regeneration on boreal mixedwood sites. However, herbicide spraying is minimized in mixedwood management because high quality hardwoods are a valuable component of the crop. Thus, partial cutting is recommended for regenerating a mixture of conifers and hardwoods. Windthrow is minimized by removing no more than 50% of the basal area and leaving the least susceptible trees (e.g., windfirm dominant trees or small-crowned trees less than 10 m tall).

If advance growth is lacking, conifers should be planted without site preparation after removing 50% of the overstory. Spot spraying of hardwood regeneration with herbicide in the second growing season would likely be required. White spruce appears to survive better than jack pine when underplanted in a partially cut mixedwood stand.

If adequate stocking of conifer advance growth exists, 40% of the overstory canopy can be removed by careful logging to release the conifers without the need for hardwood control. Overstory removal should be limited to this level if conifer advance growth is not well developed, to minimize competition from aspen suckers. Canopy manipulation affects the performance of understory species by altering microclimatic factors such as light intensity and soil temperature.

Recommendations based on early results are subject to confirmation through long-term monitoring. We need to know how productivity, stand structure, and species composition change throughout the rotation to improve the scientific basis for mixedwood policies and guidelines in Ontario. The information gained from these trials should be used to help design large-scale adaptive management projects in cooperation with companies that have mixedwood targets. Future research should address multiple resource values and use experimental units that are large enough to ensure operational relevance. Effective transfer mechanisms, such as demonstration areas, decision support software, and regular revision of mixedwood silvicultural guides, are important for incorporating results into policy and practice as quickly as possible.

Literature Cited

- Andersen, C. P., E. I. Sucoff, and R. K. Dixon. 1986. Effects of root zone temperature on root initiation and elongation in red pine seedlings. *Can. J. For. Res.* 16: 696-700.
- Comeau, P.G. and K.D. Thomas (eds.). 1996. Silviculture of temperate and boreal broadleaf-conifer mixtures. *Proc. Symp.* Feb. 28 - Mar. 1, 1995, Richmond, B.C. B.C. Min. For., Victoria, B.C. 163 p.
- Dowdy, S. and S. Wearden. 1983. *Statistics for Research.* John Wiley and Sons, N.Y. 537 p.
- Groot, A. 1999. Effects of shelter and competition on the early growth of planted white spruce (*Picea glauca*). *Can. J. For. Res.* 29: 1002-1014.
- Hannerz, M. and B. Hanell. 1997. Effects on the flora in Norway spruce forests following clearcutting and shelterwood cutting. *For. Ecol. Manage.* 90: 29-49.
- Hearnden, K.W., S.V. Millson and W.C. Wilson. 1992. A report on the status of forest regeneration. Ont. Min. Nat. Resour., Indep. For. Audit Comm., Toronto, ON. 117 p.
- Koven, A. and E. Martel. 1994. Reasons for decision and decision. Class environmental assessment by the Ministry of Natural Resources for timber management on Crown lands in Ontario. Ont. Environ. Assess. Board, Toronto, ON, No. EA-87-02. 561 p.
- Lautenschlager, R.A. 1999. Environmental resource interactions affect red raspberry growth and its competition with white spruce. *Can. J. For. Res.* 29: 906-916.
- Ludwig, J.A. and J.F. Reynolds. 1988. *Statistical Ecology.* John Wiley and Sons, N.Y. 337 p.
- MacDonald, G.B. 1995. The case for boreal mixedwood management: an Ontario perspective. *For. Chron.* 71: 725-734.
- MacDonald, G.B. and D.H. Weingartner. 1995. Definition of the Boreal Mixedwood Forest. Ont. Min. Nat. Resour., Terrestrial Ecosys. Br., Sault Ste. Marie, ON, Sci. Technol. Ser. Vol. 9, Boreal Mixedwood Notes No. 2. 6 p.
- MacDonald, G.B., D.M. Morris and P.L. Marshall. 1990. Assessing components of competition indices for young boreal plantations. *Can. J. For. Res.* 20: 1060-1068.
- McCarthy, T.G., R.W. Arnup, J. Nieppola, B.G. Merchant, K.C. Taylor and W.J. Parton. 1994. Field guide to forest ecosystems of northeastern Ontario. Ont. Min. Nat. Resour., Timmins, ON, NEST Field Guide FG-001.
- McClain, K.M. 1981. Definition and distribution of the boreal mixedwood forest in Ontario. Pp. 5-9 in R.D. Whitney and K.M. McClain (cochairs). Boreal Mixedwood Symposium. Can. For. Serv., Sault Ste. Marie, ON, COJFRC Symp. Proc. O-P-9.
- Navratil, S., K. Branter and J. Zasada. 1991. Regeneration in the mixedwoods. Pp. 32-48 in A. Shorttreid (ed.). Northern Mixedwood '89. Proc. Symp. Sept. 12-14, 1989, Fort St. John, BC. For. Can., Victoria, BC, FRDA Report 164.
- Ontario Ministry of Natural Resources. 1996. Forest resources of Ontario 1996. Queen's Printer for Ontario, Toronto, ON. 86 p.
- Perala, D.A. 1989. Scarification requirements for regenerating paper birch (*Betula papyrifera*) under shelterwood. Pp. 122-130 in R.F. Sutton and L.F. Riley (eds.). *Proc. Symp. on Equipment/Silviculture Interface in Stand Establishment Research and Operations.* For. Can., Sault Ste. Marie, ON.
- Pierpoint, G. 1981. Site types in the boreal mixedwood forest. Pp. 10-16 in R.D. Whitney and K.M. McClain (cochairs). Boreal Mixedwood Symposium. Can. For. Serv., Sault Ste. Marie, ON, COJFRC Symp. Proc. O-P-9.

- Raison, R. J. 1979. Modification of the soil environment by vegetation fires, with particular reference to nitrogen transformations: A review. *Plant Soil* 51: 73-108.
- Samoil, J.K. 1988. Management and Utilization of Northern Mixedwoods. Proc. Symp. April 11-14, 1988, Edmonton, AB. Can. For. Serv., Edmonton, AB, Inf. Rep. NOR-X-296. 163 p.
- Sampson, P.H., C.W.G. Templeton and S.J. Colombo. 1997. An overview of Ontario's stock quality assessment program. *New For.* 13: 469-487.
- Shortreid, A. 1991. Northern Mixedwood '89. Proc. Symp. Sept. 12-14, 1989, Fort St. John, BC. For. Can., Victoria, BC, FRDA Rep. 164. 160 p.
- Smith, C.R. and G.W. Crook (comps.). 1996. Advancing Boreal Mixedwood Management in Ontario. Proc. Symp. Oct. 17-19, 1995, Sault Ste. Marie, ON. Can. For. Serv., Sault Ste. Marie, ON. 239 p.
- Wagner, R.G., T.L. Noland, and G.H. Mohammed. 1996. Timing and duration of herbaceous vegetation control around four northern coniferous species. *N. Z. J. For. Sci.* 26: 39-52.
- Weingartner, D.H. and G.B. MacDonald. 1994. A survey of mixedwood research and development needs in Ontario. Ont. Min. Nat. Resour., Sault Ste. Marie, ON, For. Res. Inf. Pap. No. 118. 17 p.
- Weingartner, D.H. and G.B. MacDonald. 1995. Boreal mixedwood management philosophy. Ont. Min. Nat. Resour., Terrestrial Ecosys. Br., Sault Ste. Marie, ON, Sci. Technol. Ser. Vol. 9, Boreal Mixedwood Notes No. 3. 6 p.

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